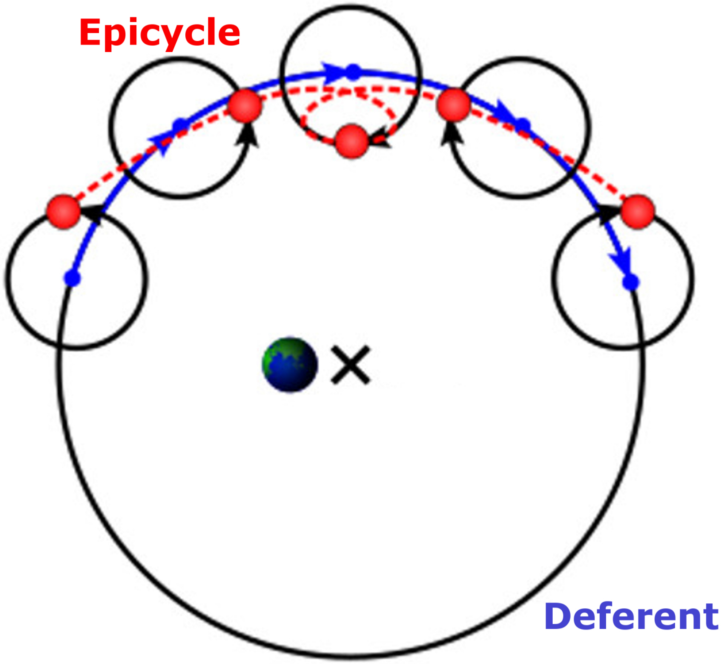
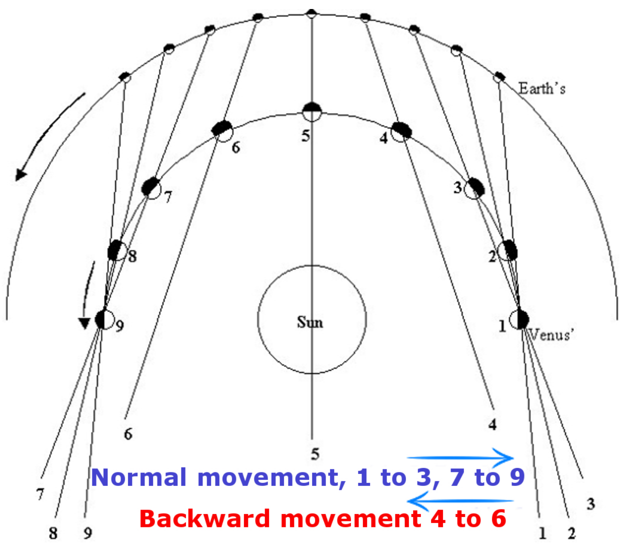
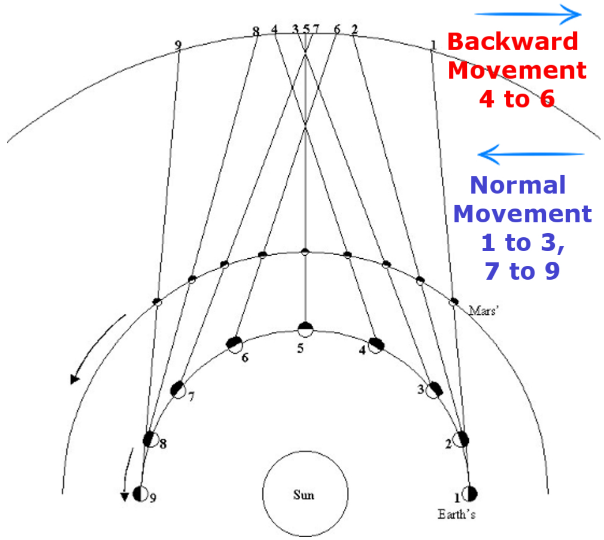
Elliptical orbits

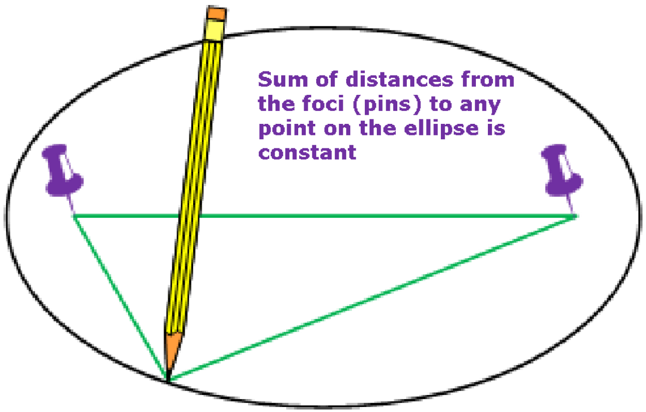


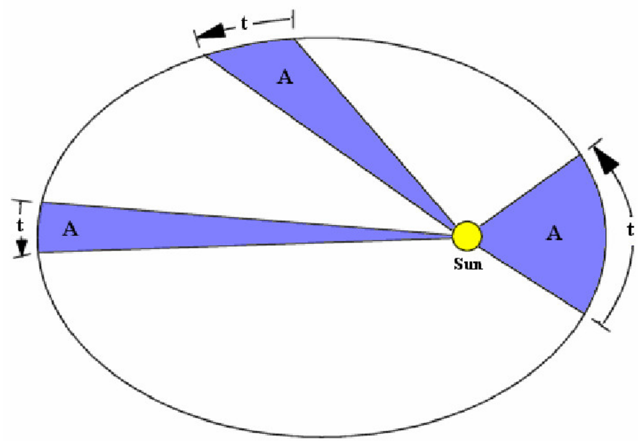
The stars appear to move in a circle around the Polaris. Many ancient cultures thought that the planets, sun and the moon would also move in a circle with respect to the fixed stars and that they would move at a constant speed. Careful observation of the sun and the moon showed that the speed of movement of the sun and the moon was not constant. The retrograde movement of the planets was a bigger challenge. The Greek astronomer Ptolemy said that the planets move in small circles called epicycles which move along a larger circle. {Picture left} A planet moving forward in the circle can still be moving backward in the epicycle. To make the calculated position of the planet agree with the observations, the center of the circle has to be fixed away from the earth, Using more than one epicycle, the calculations could be made to match the observations even better. But the question of why there are so many epicycles could not be answered. Still Problem's method of calculation was most popular till the sixteenth century.





Suggestions that the planets revolve around the sun rather than the earth were made in several ancient cultures. But, no one could show any advantage of doing so. Copernicus, in the sixteenth century was the first to show that retrograde movement of planets is easy to understand if we assume that the planets revolve around the sun. He also showed that Venus and Mercury were nearer to the sun as compared to the earth {Picture above left} while Mars, Jupiter and Saturn {Picture above right} are more distant. Retrograde motion is observed when the inner planet overtakes the outer planet. But Copernicus also assumed that the orbits of all planets were circles. Thus, epicycles became necessary to match



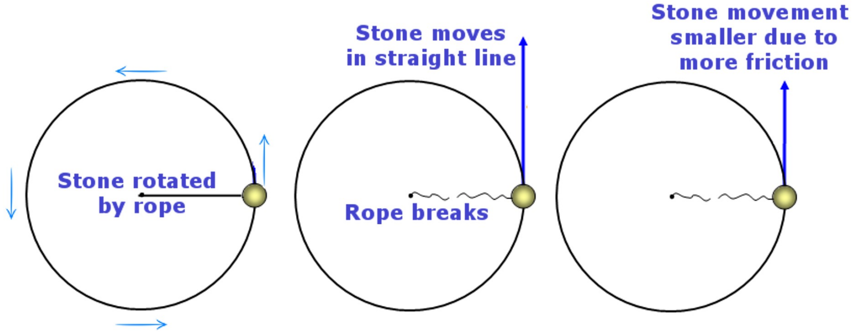


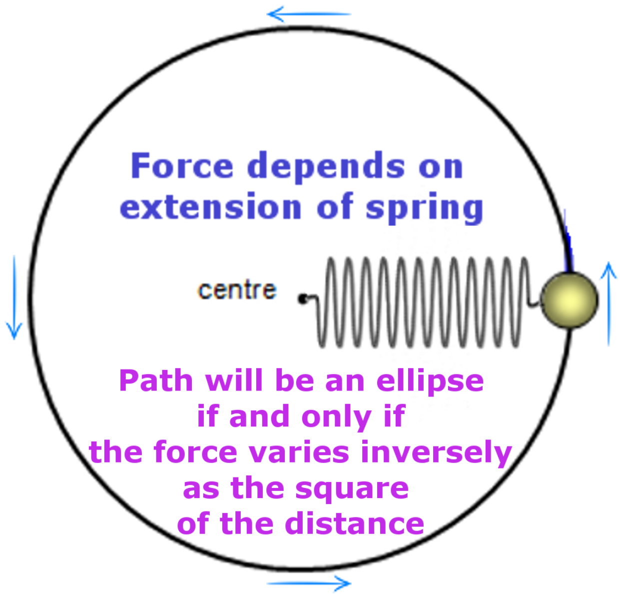
calculations and observations. Calculating using the Copernicus model swab not easier and so most people continued to use the older Ptolemy method of calculation.

Kepler was the first person to suggest that the paths followed by the planets were ellipses rather than circles. Every deformed circle is not an ellipse. In geometry, a circle is a line, all points on which are at equal distance from a single point called the center. An ellipse in geometry has two foci. The sum of the distances from any point on the ellipse to the two foci is constant. A circle is an ellipse in which the two foci are at the same point. To draw an ellipse, a piece of string is attached at two points to the paper. These form the foci. The pencil stretches the string while drawing a closed curve. {Picture above left} The sum of the distances of the points on the line to the two foci is obviously the length of the string. In

addition to saying that the paths of the planets are ellipses and the sun is at one of the foci, Kepler proposed that the line joining the sun and the planet sweeps equal areas in equal intervals of time.{Picture opposite page right} This “Kepler’s Law” dramatically changed physics. Up to that time, the position of the planet was just a number and the method of calculation was to count in a specific way. Now the area of a part of the ellipse is mathematically related to the time. Two measured quantities become part of an equation in algebra. Kepler’s work is a foundation stone of physics.

Why do planets move in elliptical orbits? We need Newton’s laws to answer this question. Day to day experience teaches that a force has to be used to move an object. But Newton proposed that force is required only to change the speed or direction of a moving object. No force is acting on an object at rest or one travelling in a straight line without any change in speed. All planets obey Kepler’s Law. All objects in the universe obey Newton’s first law of motion. A minimum speed of rotation is required to tie a stone to a rope and whirl it around horizontally. {Picture left} If the speed is low, the stone will fall towards the ground. If the rope breaks suddenly, the stone will fly off along a straight line. A force in the rope is required while the stone moves in a circle. No force is required for the

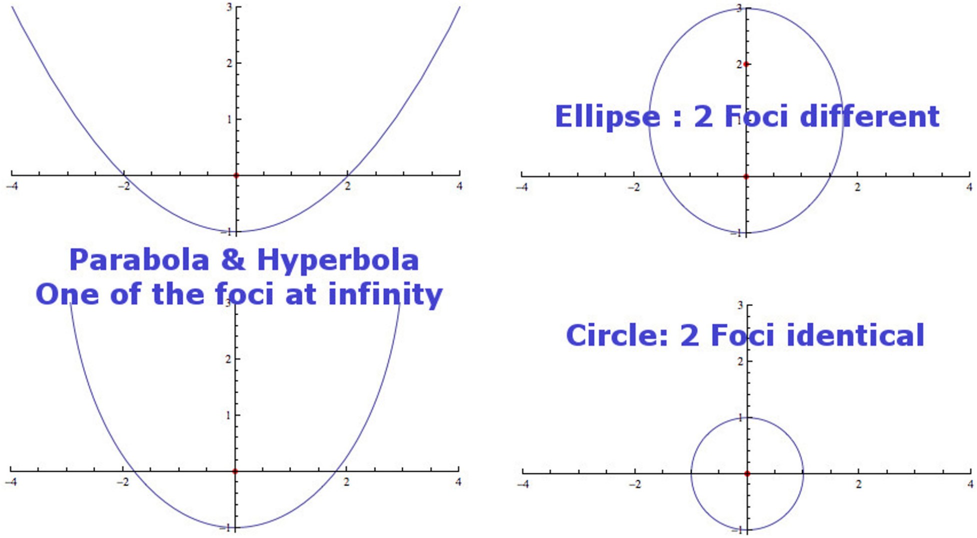


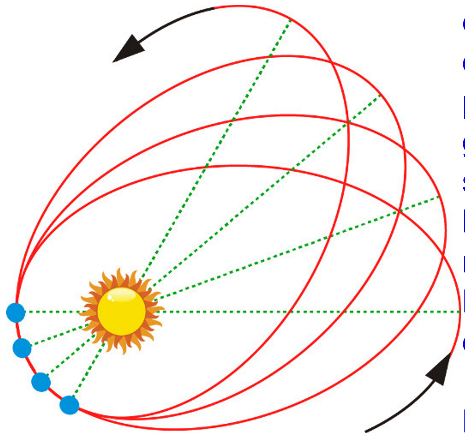


stone to move in a straight line. If there is no friction with air and no gravity of the earth, the stone will not stop. It will keep moving in a straight line with a constant speed. What if a spring is used instead of a rope? As the speed of the stone is increased the spring is stretched {Picture left}. A force is required to stretch the spring. The higher speed needs more force. Similarly, there must be a force between the focus of the ellipse and the planet for it to move in an elliptical orbit. Newton mathematically proved that the planetary orbits will be ellipses only when the force varies inversely as the square of the distance, it decreases to one fourth of its value when the distance is doubled. This is Newton's Universal Law Of Gravitation. Kepler's law is not only a method of explaining observations. It is a part of the mathematics of physics. This is not merely stating in words that a force from the sun causes the planets to move. There are claims that such arguments and guesses are found in the works of ancient cultures. But without knowing Newton's laws of motion, that a force exits only when the direction or speed of an object changes, it is impossible to know that a force causes the movement of planets. These claims about ancient texts are attempts to find new meanings

for old words and claim credit for one's own ancestors. Newton is considered one of the greatest scientists of all times because he has been able to give a mathematical form for change of gravitational force with distance and then relate this to Kepler's laws on one side and his laws of motion on the other.

Newton's universal law of gravitation is an inverse square law and so the movement of the planets is an ellipse. When the two foci are exactly at the same point, the ellipse becomes a circle. When one of the foci of an ellipse is far far away the ellipse becomes either a parabola or a hyperbola. {Picture below} All these are described by a single mathematical





equation. Circular orbits are rare in nature, but many orbits are approximately circular. The paths of many projectiles, like cannon balls, moving due to the force of gravity, are parabolas. Paths of certain interplanetary satellites are hyperbolas. This very close relationship between the experimental observations in physics and mathematics is very important and it was first found by Newton. Even today mathematics is the basic foundation of fundamental physics.

Newton's law of gravitation is universal. This force exists between every pair of bodies in nature. In addition to the gravitational force of the sun, gravitational forces due to other planets act on earth. Due to these additional forces, the elliptical orbit of the earth around the sun itself swings around the sun. {Picture above} It takes millions of years for the ellipse to complete one rotation. Using Newtonian mathematics, it is possible to calculate the movement of the ellipse and compare it with experimental results.